



DRAFT SPACE TECHNOLOGY ROADMAP OVERVIEW

NASA's integrated technology roadmap, which includes both "pull" and "push" technology strategies, considers a wide range of pathways to advance the nation's current capabilities in space. Fourteen draft Space Technology Area Roadmaps comprise the overall integrated map.

NASA developed the set of draft roadmaps for use by the National Research Council (NRC) as an initial point of departure for mapping the agency's future investments in technology. Through an open process of community engagement, the NRC will gather input, integrate and prioritize each Space Technology Area Roadmap, providing NASA with strategic guidance and recommendations that inform the technology investment decisions of NASA's space technology activities. Because it is difficult to predict the wide range of future advances in these areas, NASA expects to update the integrated technology roadmap on a regular basis.

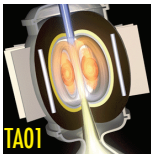
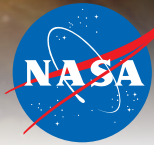
The overall roadmap spans NASA's significant technology development efforts and has relevance to all of NASA Mission Directorates, as well as the Space Technology programs managed by the Office of the Chief Technologist. The 14 Space Technology Areas focus on strategically identified areas where significant technology investments are anticipated, and where substantial enhancements in NASA mission capabilities are needed. Past NASA technology roadmapping efforts, as well as inputs from the Mission Directorates and the NASA Centers, served as the starting point for each Technology Area roadmap.

For each Technology Area, an internal NASA team of Subject Matter Experts was established. As needed, these experts reached out to other experts throughout NASA. In some cases, the teams reached out to other governmental agency experts, and to industry experts through fact-finding meetings. As shown in Figure 1, the teams created a Technology Area Breakdown Structure. Each team then:

- Identified the top technical challenges that, if met, would achieve needed performance
- Identified the mission "pull" technologies needed to support the increased capabilities demanded by future planned NASA missions.
- Identified emerging "push" technologies that could meet NASA's long-term strategic challenges.

The teams correlated their technology pathways with the existing set of NASA missions (i.e., mission "pull") to create time-phased plans for technology development. In the case of "push" technologies, the teams conceived additional missions enabled by these technologies that meet the agency's strategic plans in alternate or novel ways. This time-phased correlation is visualized in Technology Area Strategic Roadmap figures in each report. The teams also identified NASA technology advances synergistic to other national needs, such as energy generation and storage, communications, health and medicine, and national security.

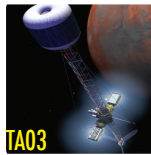
These draft reports are not budget-driven or budget-constrained. In the next step of this process, NASA will develop preliminary cost estimates and prioritizations for the individual technologies. These activities will include understanding of the ongoing investments of other Federal agencies, universities and the private sector. This set of draft products provides a critical snapshot of specific challenges and technologies, as well as how these technologies can support NASA's missions and contribute to significant national needs. These reports will be used as a strategic guide to inform the agency's budget formulation and prioritization process; organize the Office of Chief Technologist solicitations; and initiate an open process of community engagement through a National Research Council space technology evaluation and prioritization process.



TA01



TA02



TA03



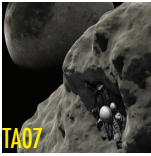
TA04



TA05



TA06



TA07



TA08

TA01 • LAUNCH PROPULSION SYSTEMS

SOLID ROCKET PROPULSION SYSTEMS

- Propellants
- Case Materials
- Nozzle Systems
- Hybrid Rocket Propulsion Systems
- Fundamental Solid Propulsion Technologies

LIQUID ROCKET PROPULSION SYSTEMS

- LH₂/LOX Based
- RP/LOX Based
- CH₄/LOX Based
- Detonation Wave Engines (Closed Cycle)
- Propellants
- Fundamental Liquid Propulsion Technologies

AIR BREATHING PROPULSION SYSTEMS

- TBCC
- RBCC
- Detonation Wave Engines (Open Cycle)
- Turbine Based Jet Engines (Flyback Boosters)
- Ramjet/Scramjet Engines (Accelerators)
- Deeply-cooled Air Cycles
- Air Collection & Enrichment System
- Fundamental Air Breathing Propulsion Technologies

ANCILLARY PROPULSION SYSTEMS

- Auxiliary Control Systems
- Main Propulsion Systems (Excluding Engines)
- Launch Abort Systems
- Thrust Vector Control Systems
- Health Management & Sensors
- Pyro & Separation Systems
- Fundamental Ancillary Propulsion Technologies

UNCONVENTIONAL / OTHER PROPULSION SYSTEMS

- Ground Launch Assist
- Air Launch / Drop Systems
- Space Tether Assist
- Beamed Energy / Energy Addition
- Nuclear
- High Energy Density Materials/Propellants

TA02 • IN-SPACE PROPULSION TECHNOLOGIES

CHEMICAL PROPULSION

- Liquid Storable
- Liquid Cryogenic
- Gels
- Solid
- Hybrid
- Cold Gas/Warm Gas
- Micro-propulsion

NON-CHEMICAL PROPULSION

- Electric Propulsion
- Solar Sail Propulsion
- Thermal Propulsion
- Tether Propulsion

ADVANCED (TRL <3) PROPULSION TECHNOLOGIES

- Beamed Energy Propulsion
- Electric Sail Propulsion
- Fusion Propulsion
- High Energy Density Materials
- Antimatter Propulsion
- Advanced Fission
- Breakthrough Propulsion

SUPPORTING TECHNOLOGIES

- Engine Health Monitoring & Safety
- Propellant Storage & Transfer
- Materials & Manufacturing Technologies
- Heat Rejection
- Power

TA03 • SPACE POWER & ENERGY STORAGE

POWER GENERATION

- Energy Harvesting
- Chemical (Fuel Cells, Heat Engines)
- Solar (Photo-Voltaic & Thermal)
- Radioisotope
- Fission
- Fusion

ENERGY STORAGE

- Batteries
- Flywheels
- Regenerative Fuel Cells

POWER MANAGEMENT & DISTRIBUTION

- FDIR
- Management & Control
- Distribution & Transmission
- Wireless Power Transmission
- Conversion & Regulation

CROSS CUTTING TECHNOLOGY

- Analytical Tools
- Green Energy Impact
- Multi-functional Structures
- Alternative Fuels

TA04 • ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

SENSING & PERCEPTION

- Stereo Vision
- LIDAR
- Proximity Sensing
- Sensing Non-Geometric Terrain Properties
- Estimating Terrain Mechanical Properties
- Tactile Sensing Arrays
- Gravity Sensors & Celestial Nav.
- Terrain Relative Navigation
- Real-time Self-calibrating of Hand-eye Systems

MOBILITY

- Simultaneous Localiz. & Mapping
- Hazard Detection Algorithms
- Active Illumination
- 3-D Path Planning w/ Uncertainty
- Long-life Extr. Enviro. Mechanisms
- Robotic Jet Backpacks
- Smart Tethers
- Robot Swarms
- Walking in Micro-g

MANIPULATION

- Motion Planning Alg., High DOF
- Sensing & Control
- Robot Arms (light, high strength)
- Dexterous Manipul., Robot Hands
- Sensor Fusion for Grasping
- Grasp Planning Algorithms
- Robotic Drilling Mechanisms
- Multi-arm / Finger Manipulation
- Planning with Uncertainty

HUMAN-SYSTEMS INTEGRATION

- Crew Decision Support Systems
- Immersive Visualization
- Distributed Collaboration
- Multi Agent Coordination
- Haptic Displays
- Displaying Range Data to Humans

AUTONOMY

- Spacecraft Control Systems
- Vehicle Health, Prog/Diag Systems
- Human Life Support Systems
- Planning/Scheduling Resources
- Operations
- Integrated Systems Health Management
- FDIR & Diagnosis
- System Monitoring & Prognosis
- V&V of Complex Adaptive Sys's
- Automated Software Generation
- Software Reliability
- Semi Automatic Systems

AUTON. RENDEZVOUS & DOCKING

- Rendezvous and Capture
- Low impact & Androgenous
- Docking Systems & Interfaces
- Relative Navigation Sensors
- Robust AR&D GN&C Algorithms & FSW
- Onboard Mission Manager
- AR&D Integration & Standardiz.n

RTA SYSTEMS ENGINEERING

- Human safety
- Refueling Interfaces & Assoc. Tools
- Modular / Serviceable Interfaces
- High Perf., Low Power Onboard Computers
- Environment Tolerance
- Thermal Control
- Robot-to-Suit Interfaces
- Common Human-Robot Interfaces
- Crew Self Sufficiency

TA05 • COMMUNICATION & NAVIGATION

OPTICAL COMM. & NAVIGATION

- Detector Development
- Large Apertures
- Lasers
- Acquisition & Tracking
- Atmospheric Mitigation

RADIO FREQUENCY COMMUNICATIONS

- Spectrum Efficient Technologies
- Power Efficient Technologies
- Propagation
- Flight & Ground Systems
- Earth Launch & Reentry Comm.
- Antennas

INTERNETWORKING

- Disruptive Tolerant Networking
- Adaptive Network Topology
- Information Assurance
- Integrated Network Management

POSITION, NAVIGATION, AND TIMING

- Timekeeping
- Time Distribution
- Onboard Auto Navigation & Maneuver
- Sensors & Vision Processing Systems
- Relative & Proximity Navigation
- Auto Precision Formation Flying
- Auto Approach & Landing

INTEGRATED TECHNOLOGIES

- Radio Systems
- Ultra Wideband
- Cognitive Networks
- Science from the Comm. System
- Hybrid Optical Comm. & Nav. Sensors
- RF/Optical Hybrid Technology

REVOLUTIONARY CONCEPTS

- X-Ray Navigation
- X-Ray Communications
- Neutrino-Based Navigation & Tracking
- Quantum Key Distribution
- Quantum Communications
- SQIF Microwave Amplifier
- Reconfigurable Large Apertures

TA06 • HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

ENVIRONMENTAL CONTROL & LIFE SUPPORT SYSTEMS & HABITATION SYS.

- Air Revitalization
- Water Recovery & Management
- Waste Management
- Habitation

EXTRAVEHICULAR ACTIVITY SYSTEMS

- Pressure Garment
- Portable Life Support System
- Power, Avionics and Software

HUMAN HEALTH & PERFORMANCE

- Medical Diagnosis / Prognosis
- Long-Duration Health
- Behavioral Health & Performance
- Human Factors & Performance

ENVIRONMENTAL MONITORING, SAFETY & EMERGENCY RESPONSE

- Sensors: Air, Water, Microbial, etc.
- Fire: Detection, Suppression
- Protective Clothing / Breathing
- Remediation

RADIATION

- Risk Assessment Modeling
- Radiation Mitigation
- Protection Systems
- Space Weather Prediction
- Monitoring Technology

TA07 • HUMAN EXPLORATION DESTINATION SYSTEMS

IN-SITU RESOURCE UTILIZATION

- Destination Reconnaissance, Prospecting, & Mapping
- Resource Acquisition
- Consumables Production
- Manufacturing & Infrastructure Emplacement

SUSTAINABILITY & SUPPORTABILITY

- Logistics Systems
- Maintenance Systems
- Repair Systems

“ADVANCED” HUMAN MOBILITY SYSTEMS

- EVA Mobility
- Surface Mobility
- Off-Surface Mobility

“ADVANCED” HABITAT SYSTEMS

- Integrated Habitat Systems
- Habitat Evolution

MISSION OPERATIONS & SAFETY

- Crew Training
- Environmental Protection
- Remote Mission Operations
- Planetary Safety

CROSS-CUTTING SYSTEMS

- Modeling, Simulations & Destination Characterization
- Construction & Assembly
- Dust Prevention & Mitigation

TA08 • SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

REMOTE SENSING INSTRUMENTS / SENSORS

- Detectors & Focal Planes
- Electronics
- Optical Components
- Microwave / Radio
- Lasers
- Cryogenic / Thermal

OBSERVATORIES

- Mirror Systems
- Structures & Antennas
- Distributed Aperture

IN-SITU INSTRUMENTS / SENSOR

- Particles: Charged & Neutral
- Fields & Waves
- In-Situ



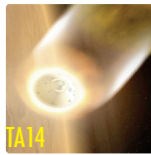
TA11



TA12



TA13



TA14

TA09 • ENTRY, DESCENT & LANDING SYSTEMS

AEROASSIST & ATMOSPHERIC ENTRY

- Rigid Thermal Protection Systems
- Flexible Thermal Protection Systems
- Rigid Hypersonic Decelerators
- Deployable Hypersonic Decelerators
- Instrumentation & Health Monitoring
- Entry Modeling & Simulation

DESCENT

- Attached Deployable Decelerators
- Trailing Deployable Decelerators
- Supersonic Retropropulsion
- GN&C Sensors
- Descent Modeling & Simulation

LANDING

- Touchdown Systems
- Egress & Deployment Systems
- Propulsion Systems
- Large Body GN&C
- Small Body Systems
- Landing Modeling & Simulation

VEHICLE SYSTEMS TECHNOLOGY

- Architecture Analyses
- Separation Systems
- System Integration & Analyses
- Atmosphere & Surface Characterization

TA10 • NANOTECHNOLOGY

ENGINEERED MATERIALS & STRUCTURES

- Lightweight Structures
- Damage Tolerant Systems
- Coatings
- Adhesives
- Thermal Protection & Control

ENERGY GENERATION & STORAGE

- Energy Storage
- Energy Generation

PROPULSION

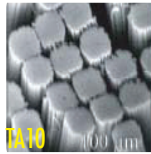
- Propellants
- Propulsion Components
- In-Space Propulsion

SENSORS, ELECTRONICS & DEVICES

- Sensors & Actuators
- Nanoelectronics
- Miniature Instruments



TA09



TA10

TA11 • MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

COMPUTING

- Flight Computing
- Ground Computing

MODELING

- Software Modeling & Model-Checking
- Integrated Hardware & Software Modeling
- Human-System Performance Modeling
- Science & Engineering Modeling
- Frameworks, Languages, Tools & Standards

SIMULATION

- Distributed Simulation
- Integrated System Lifecycle Simulation
- Simulation-Based Systems Engineering
- Simulation-Based Training & Decision Support Systems

INFORMATION PROCESSING

- Science, Engineering & Mission Data Lifecycle
- Intelligent Data Understanding
- Semantic Technologies
- Collaborative Science & Engineering
- Advanced Mission Systems

TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

MATERIALS

- Lightweight Structure
- Computational Design
- Flexible Material Systems
- Environment
- Special Materials

STRUCTURES

- Lightweight Concepts
- Design & Certification Methods
- Reliability & Sustainment
- Test Tools & Methods
- Innovative, Multifunctional Concepts

MECHANICAL SYSTEMS

- Deployables, Docking and Interfaces
- Mechanism Life Extension Systems
- Electro-mechanical, Mechanical & Micromechanisms
- Design & Analysis Tools and Methods
- Reliability / Life Assessment / Health Monitoring
- Certification Methods

MANUFACTURING

- Manufacturing Processes
- Intelligent Integrated Manufacturing and Cyber Physical Systems
- Electronics & Optics Manufacturing Process
- Sustainable Manufacturing

CROSS-CUTTING

- Nondestructive Evaluation & Sensors
- Model-Based Certification & Sustainment Methods
- Loads and Environments

TA13 • GROUND & LAUNCH SYSTEMS PROCESSING

TECHNOLOGIES TO OPTIMIZE THE OPERATIONAL LIFE-CYCLE

- Storage, Distribution & Conservation of Fluids
- Automated Alignment, Coupling, & Assembly Systems
- Autonomous Command & Control for Ground and Integrated Vehicle/Ground Systems

ENVIRONMENTAL AND GREEN TECHNOLOGIES

- Corrosion Prevention, Detection, & Mitigation
- Environmental Remediation & Site Restoration
- Preservation of Natural Ecosystems
- Alternate Energy Prototypes

TECHNOLOGIES TO INCREASE RELIABILITY AND MISSION AVAILABILITY

- Advanced Launch Technologies
- Environment-Hardened Materials and Structures
- Inspection, Anomaly Detection & Identification
- Fault Isolation and Diagnostics
- Prognostics Technologies
- Repair, Mitigation, and Recovery Technologies
- Communications, Networking, Timing & Telemetry

TECHNOLOGIES TO IMPROVE MISSION SAFETY/MISSION RISK

- Range Tracking, Surveillance & Flight Safety Technologies
- Landing & Recovery Systems & Components
- Weather Prediction and Mitigation
- Robotics / Telerobotics
- Safety Systems

TA14 • THERMAL MANAGEMENT SYSTEMS

CRYOGENIC SYSTEMS

- Passive Thermal Control
- Active Thermal Control
- Integration & Modeling

THERMAL CONTROL SYSTEMS

- Heat Acquisition
- Heat Transfer
- Heat Rejection & Energy Storage

THERMAL PROTECTION SYSTEMS

- Entry / Ascent TPS
- Plume Shielding (Convective & Radiative)
- Sensor Systems & Measurement Technologies

Figure 1

Space Technology Roadmaps STR • TABS

TECHNOLOGY AREA BREAKDOWN STRUCTURE